X-615-63-102

N64 10109

CODE-1

(NASA TMX-51059)

24p.

INVESTIGATION OF HF AND VHF ROCKET-BORNE SHROUD ANTENNAS

BY

G. H. SPAID

AND

J. R. HAGEMEYER

MAY 1963 24 p refs

Corp. author: NASA

GODDARD SPACE FLIGHT CENTER

GREENBELT, MD.

K602/307

OTS: $2.60 ph, $0.92 mf

INVESTIGATION OF HF AND VHF ROCKET-BORNE SHROUD ANTENNAS

by

G. H. Spaid and J. R. Hagemeyer

NASA-Goddard Space Flight Center
Space Sciences Division
Greenbelt, Maryland

M A Y 1 9 6 3

INVESTIGATION OF HF AND VHF ROCKET-BORNE SHROUD ANTENNAS

by

G. H. Spaid and J. R. Hagemeyer

NASA-Goddard Space Flight Center
Space Sciences Division
Greenbelt, Maryland

ABSTRACT

10109

The shroud antenna system originally developed by the Ballistic Research Laboratory for their 38 Mc/76 Mc DOVAP tracking system, has been modified at GSFC to meet the requirements of ionospheric experiments in which 24.5 and 73.6 Mc CW signals are transmitted from a rocket to the ground. These modifications were accompanied by significant improvements in matching and in pre-flight antenna adjustment techniques. In addition, it was found that shroud antennas could be used quite satisfactorily at frequencies lower than those used in the DOVAP system. Experimental results from two rocket flights showed that the antenna performance was in good agreement with theoretical predictions.

AUTHOR

INVESTIGATION OF HF AND VHF ROCKET-BORNE SHROUD ANTENNAS

by

G. H. Spaid and J. R. Hagemeyer

NASA-Goddard Space Flight Center
Space Sciences Division
Greenbelt, Maryland

I. INTRODUCTION

The antennas to be discussed are currently a part of the instrumentation used by GSFC for the measurement of electron densities in the ionosphere. The rocket-borne propagation technique[1] used for this purpose is based upon the measurement of the dispersive Doppler effect of two harmonically related frequencies. The antenna used to radiate the lower of the two frequencies presents the more difficult problem. Experiments conducted in the past using various choices of the lower frequency (4.27 Mc., 7.75 Mc. and 12.27 Mc.) have indicated that the quality of the ionospheric measurements does not deteriorate when the low frequency was raised from 4.27 Mc to 12.27 Mc. Furthermore, raising the low frequency leads to significant simplifications in both the antenna design and the data analysis.

Various types of extendable antennas[2,3] have previously been used successfully in the program. Although these antennas were electrically very satisfactory, the required extension introduced mechanical complications which resulted in reduced reliability.

Another serious drawback in small payloads was the storage space required for these antennas. In view of the changes in operating frequencies for the CW propagation experiment to 24.53 Mc and 73.6 Mc, it appeared feasible to use modified versions of the DOVAP shroud antennas which require no extension and no payload storage space. The investigation of this problem led to improvements in the basic design of the antenna networks and the entire system was successfully tested in two rocket flights. The present report discusses in detail the modified antenna design and the results of the rocket tests. The modification included the use of a switched attenuator to prevent antenna breakdown[2] in the 60 to 100 km altitude range.

II. DISCUSSION OF THE STANDARD 76 MC. DOVAP SHROUD ANTENNA

Mechanical Design

The 76 Mc shroud antennas[4] were designed and developed by the Ballistic Research Laboratories at the Aberdeen Proving Ground, Md., as a part of their DOVAP instrumentation for determining rocket trajectories during the IGY launchings at Fort Churchill, Canada. These antennas are normally mounted and phased to approximate a one turn rectangular loop with the rocket axis in the plane of the loop and parallel to two sides of the loop. The loop is made of two shrouds clamped on opposite sides of the rocket. A flat copper foil conductor that has been formed into a semicircular shape is molded between two layers of a heat resistant fiberglas-plastic laminate. These shrouds are illustrated by Figures 1 and 2.

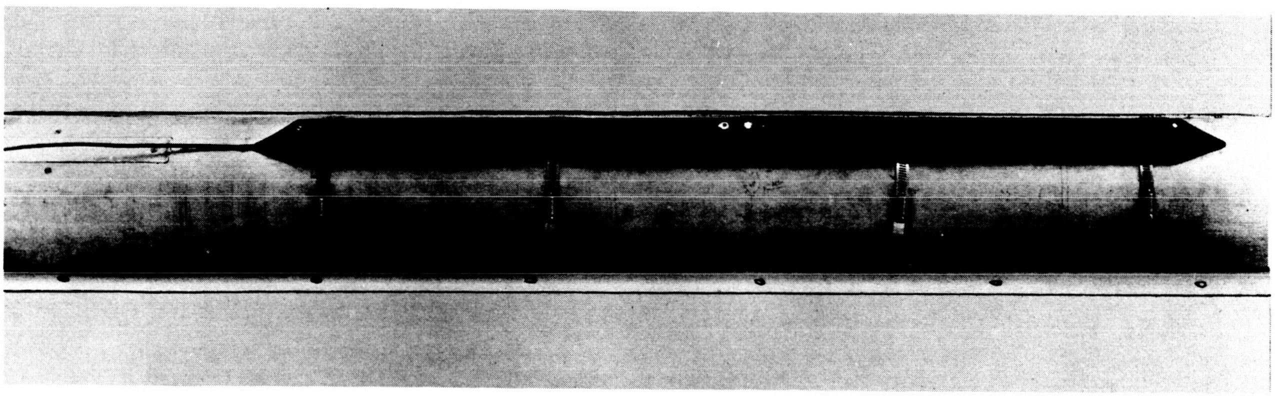

FIGURE 1

73.6 Mc. Shroud Mounted On A
Ground Plane

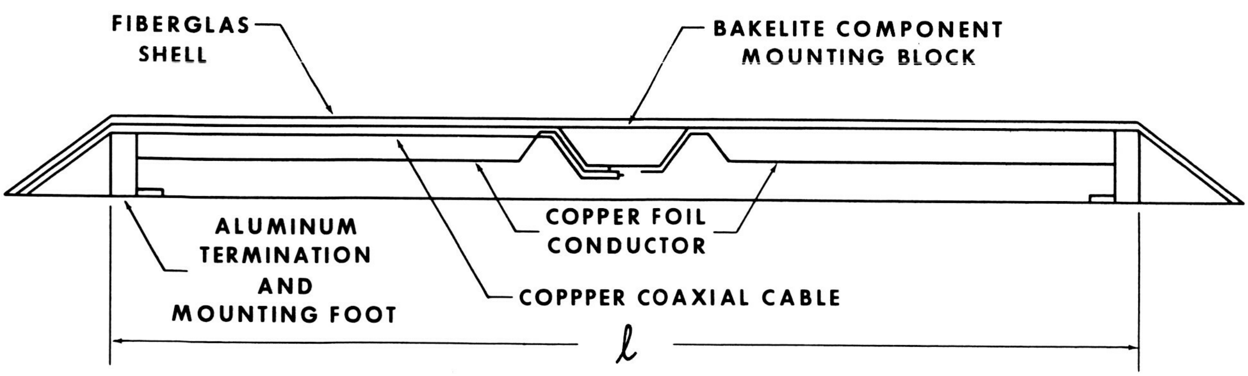

FIGURE 2

Side View of Shroud (Cutaway)

The 76 Mc. shroud is about 38 inches long, the width is 1½ inches and it extends 1¼ inches from the rocket. The copper foil conductor is broken in the middle of the shroud to form two terminals. The ends are electrically connected to the rocket at each end of the shroud when the antennas are mounted on the rocket. A small solid copper shielded coaxial cable is mounted near and connected in several places to the inner surface of the copper foil from one end to the center of the shroud. Thus, in operation the cable shield is excited to the same potential as the conductor to which it is attached. A schematic of a shroud is shown in Figure 3. A block of bakelite is provided at the center of the shroud to serve as a mounting for the components used to match the shroud terminal impedance to the coaxial cable.

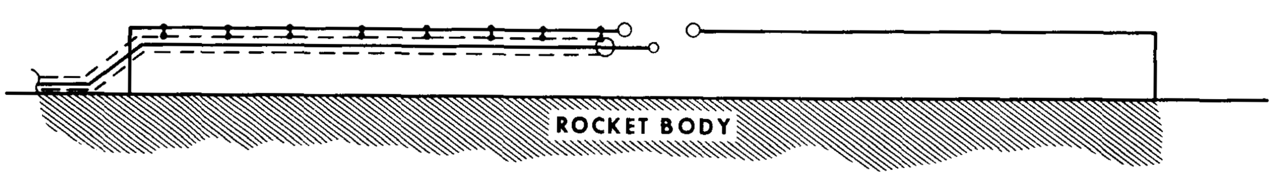

FIGURE 3

Schematic of Shroud

Theory of Operation

For loop antennas in which the dimensions are small compared with a wavelength, the current is usually assumed to be constant throughout the loop and the radiation pattern is practically independent of the shape of the loop. The field strength is given by[5]

$$E = \frac{120\pi^2}{d} N(A/\lambda^2) I \cos\theta$$

where E = field strength, volts per meter

d = distance, meters

N = number of loop turns

A = area of loop, square meters

λ = wavelength, meters

A/λ^2 = area of loop, wavelengths squared

I = loop current, amperes

θ = angle with respect to the plane of the loop.

The shrouds on opposite sides of the rocket are oppositely phased so that the current flows in the same direction around the loop. For purposes of calculating field strength the effective area A of the antenna is taken to be the total area between the antenna and the rocket body or

$$A = 2\,\ell\,d$$

where ℓ is shown in Figure 2 and d is shown in Figure 4.

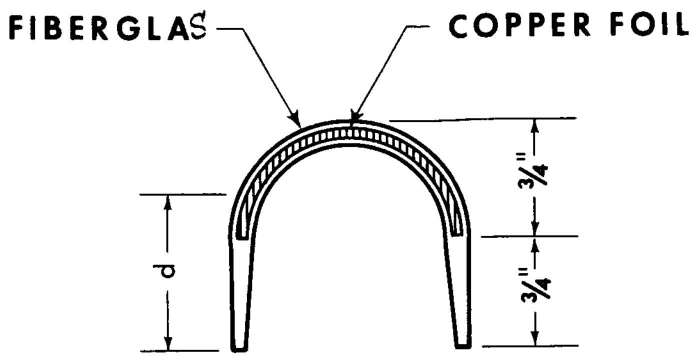

FIGURE 4

Shroud Antenna Cross Section

For the 76 Mc shrouds ℓ = 83 cm and d = 2.54 cm. Since the loop dimensions are small compared to one wavelength, the impedance of the shroud antenna can be represented by a small resistance in series with a large inductive reactance.

Matching Techniques

The 76 Mc shroud antennas are usually matched with a transformer whose secondary is in series with a capacitor across the terminals of the shroud; the transformer input winding is connected to the coaxial cable that terminates at the center of the shroud. Equal lengths of cable from each shroud transformer are connected in parallel at an L matching network which matches the parallel impedance presented by the shrouds to a cable connected to a transmitter or receiver in the payload. The phase inversion required between the two shrouds is accomplished by reversing the transformer leads connected to the coaxial cable on one shroud of each set.

The standard method of adjusting the matching networks is accomplished after the complete antenna system has been mounted on the rocket. A test oscillator or transmitter with a power output of about one or two watts is first connected to each shroud through a directional coupler. Each shroud matching network is adjusted individually for a lowest standing-wave ratio. The shrouds are then fed in parallel and readjusted to compensate for the coupling between them. Finally, using a field strength meter as an indicator of phasing, the networks are readjusted for minimum VSWR and 180 degrees phase difference.

This method of adjustment does not take advantage of the symmetry of the shrouds to eliminate the problem of coupling between them while making individual tuning and matching adjustments; the adjustments are not independent of each other. The use of test equipment that measures VSWR does not indicate what specific adjustment should be made to improve the match. In general, a trial adjustment is made and the test equipment is then used to indicate whether or not an improvement in adjustment has been obtained. Proximity of surrounding objects influence the accuracy of adjustment that can be obtained. The accuracy of the resulting adjustment obtained by this method can vary greatly, depending upon the skill and judgment of the technician.

Since the adjustments are often made on a loaded rocket there is a danger that the radio frequency power used (1 to 2 watts) will ignite the rocket propellant. Finally, when all adjustments are completed, there is considerable uncertainty as to the matching efficiency which has been achieved.

III. REDESIGN OF THE VHF SHROUD ANTENNA SYSTEM

In an effort to simplify the above adjustment procedures, the authors were led to consider the use of ground plane techniques which take advantage of the antenna symmetry. It was also found necessary to improve the circuit design since the original tuning controls were very difficult to adjust to the required accuracy. The first step in redesigning the antenna systems was to measure accurately the terminal impedance of the shroud antennas. The terminal impedance was found to be 8.61 + j191 ohms at 73.6 megacycles, which lends itself very well to matching with an L section network[7]. The arrangement used to match the shroud to the cable is shown in Figure 5.

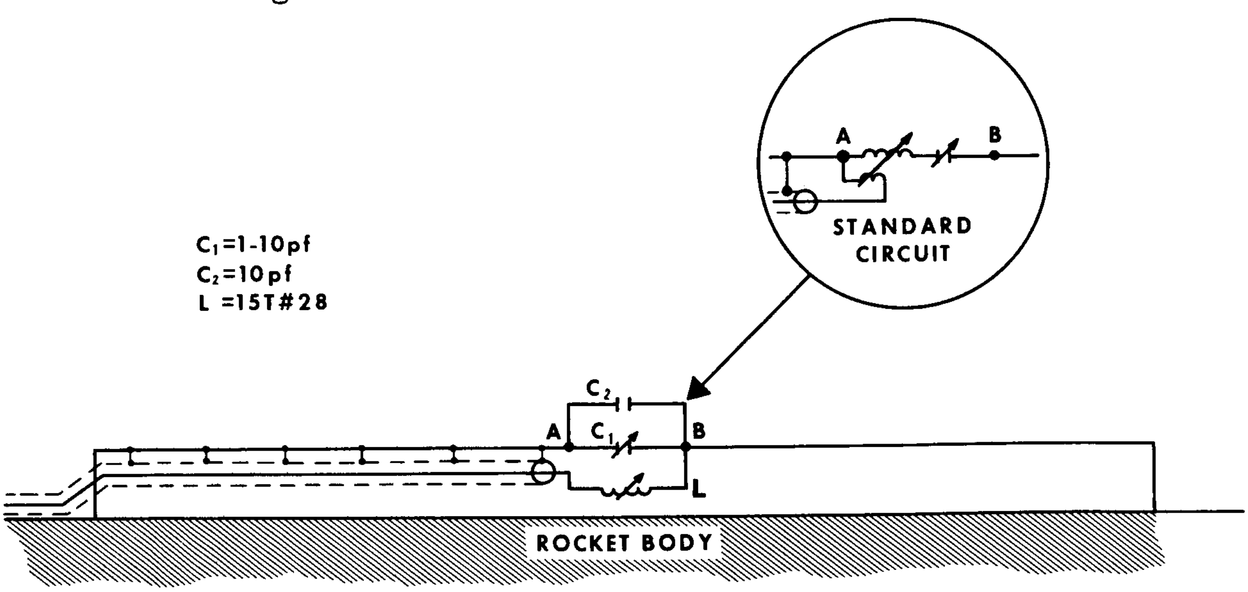

FIGURE 5
Schematic of 73.6 Mc. Shroud

Since the L section required to match the impedance corresponds to a loaded Q of only nine, the efficiency can be made high and adjustments are not critical. Since the redesigned matching network does not provide an easy method of inverting the phase at one of the shrouds, the phase shift is accomplished with a half-wave cable included in the matching network (Figure 6) located between the two shroud cables and the transmitter cable.

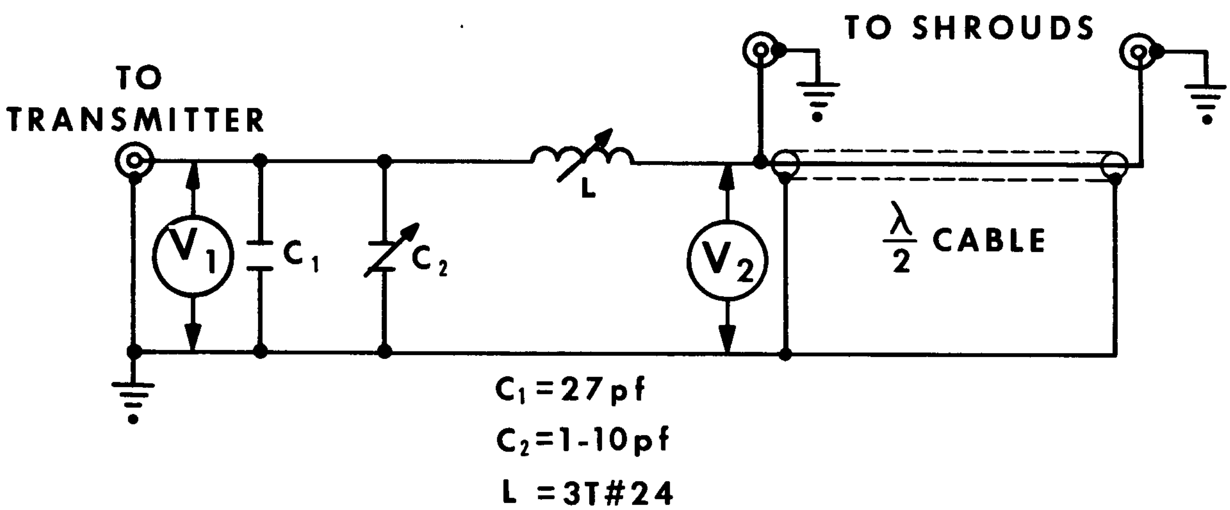

FIGURE 6

73.6 Mc. Matching and Phase inverting Network

Several measurements were made to determine the effects of removing and remounting the shrouds on the half-racket. In the worst cases the change in the value of the antenna terminal impedance was only about five per cent. No variable is introduced by the matching network and half-wave cable shown in Figure 6 since they are adjusted with dummy loads. It is therefore practical to preadjust the entire antenna system before it is taken to the field and installed on the rocket. Built-in diode monitors reading voltages V_1 and V_2 (Figure 6) are observed during the preflight check to insure that the final installation has been correctly done. A further advantage of the new design is in the elimination of the antenna matching transformer which leads to somewhat lower RF voltages near the antenna terminals, and helps overcome the problems of RF breakdown in the critical pressure range.

IV. DESIGN OF THE 24.53 MC. SHROUD ANTENNA SYSTEM.

Shroud antennas having the same physical cross section as the 73.6 Mc. shrouds and an overall length of seventy inches were used at 24.53 Mc. (Figure 7) The terminal impedance measured on the ground plane was 1.24 + j105 ohms. These antennas were matched with two series capacitors (C_1 and C_2 of Fig. 8) adjusted to match the shroud impedance to the cable at the terminal common to both capacitors.

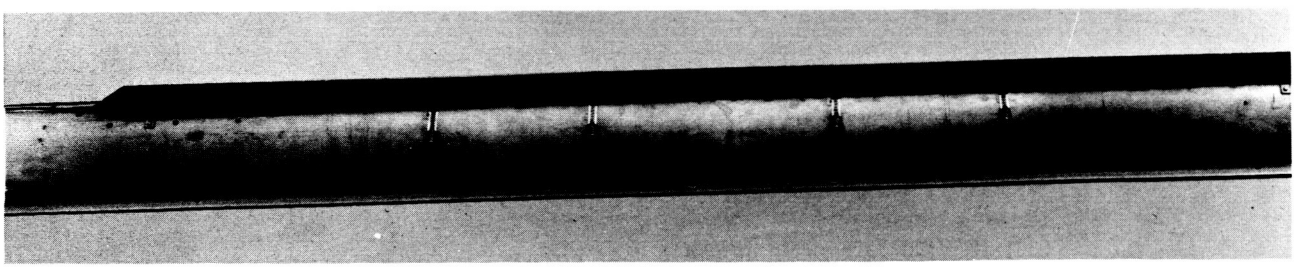

FIGURE 7

24.53 Mc. Shroud Mounted on A Ground Plane

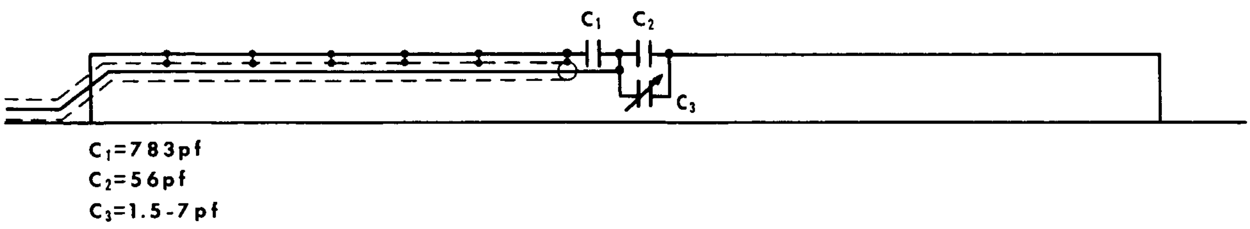

FIGURE 8

Schematic of 24.53 Mc. Shroud

The principal advantage of this design is the high efficiency of the matching network. The network also has the advantages of being simple and stable. The capacitor C in parallel with the cable is not extremely critical and is selected (or trimmed) rather than adjusted. Since the individual shroud matching-network does not provide for the 180° phase difference that is required, the phase reversal is accomplished in the matching box (Figure 9) located between the two shroud cables and the transmitter cable. The 24.53 Mc antenna system is pre-adjusted, installed on the rocket and checked in a manner similar to that described for the 73.6 Mc antenna system.

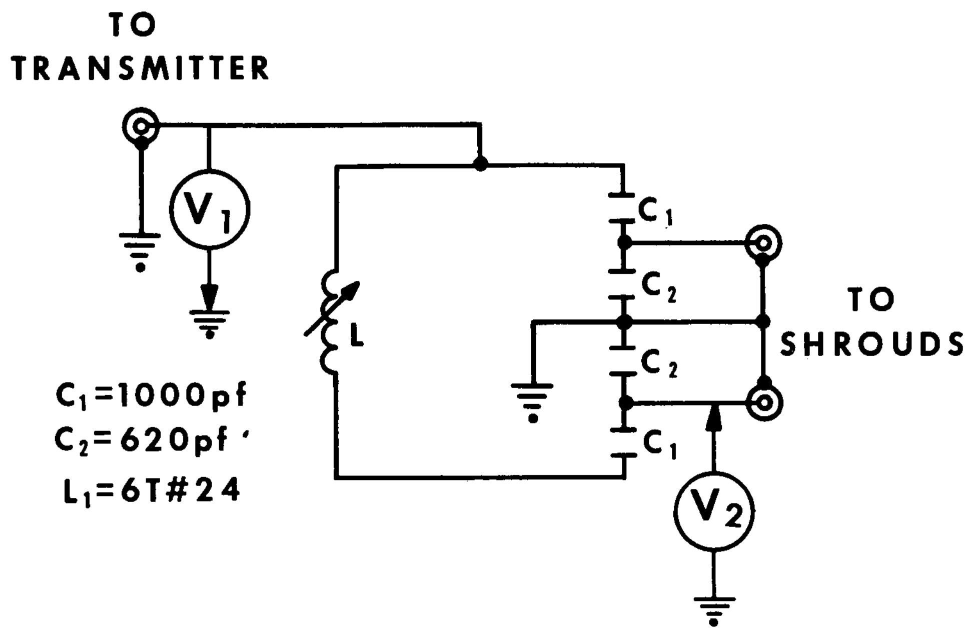

FIGURE 9

24.53 Mc. Matching and Phase Inverting Network

V. PERFORMANCE OF ANTENNAS DURING THE ROCKET FLIGHTS.

Nike-Apache 14.31

The graphs of received signal amplitude versus slant range for Nike-Apache 14.31 are given for both frequencies in Figures 10 and 11. Tests conducted in a vacuum chamber before the 14.31 flight had indicated that breakdown would not occur. However, breakdown did occur at both frequencies during the Apache 14.31 flight as indicated on the signal amplitude graphs. Richard[8] who had a similar experience at the Ballistic Research Laboratory suggested that an ionization source in the chamber would help initiate the discharge and make the test more realistic.

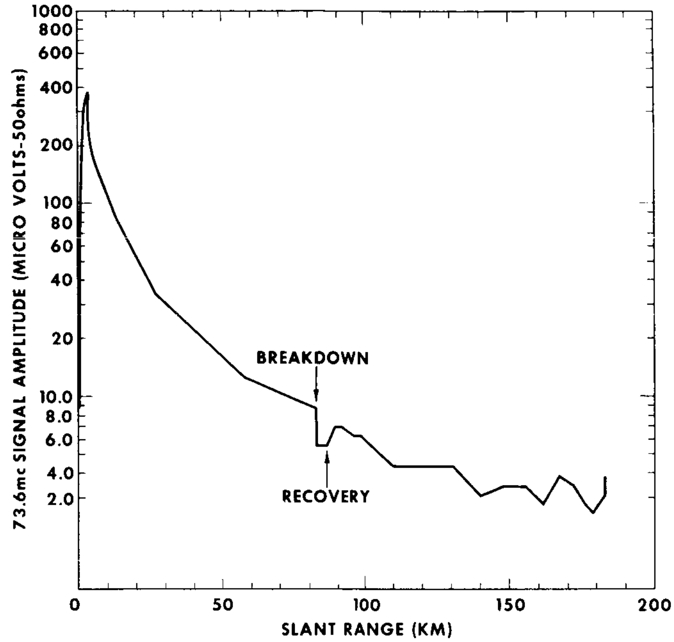

FIGURE 10

73.6 Mc. Received Signal Amplitude for Nike Apache 14.31

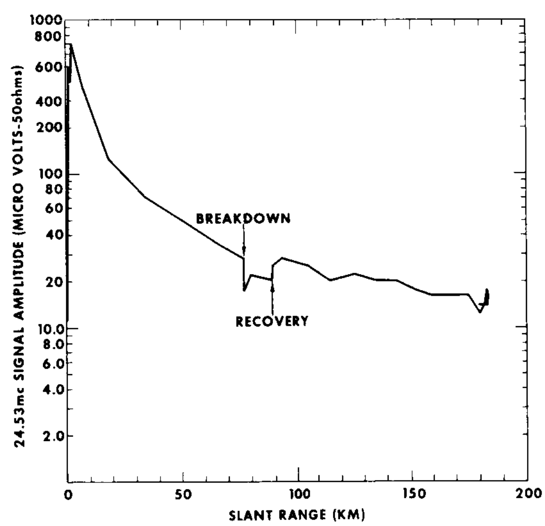

FIGURE 11

24.53 Mc. Received Signal Amplitude for Nike Apache 14.31

The rectangular notch beginning at 77 km and ending at 89 km slant range (74 km and 85 km altitude) on the 24.53 Mc graph is due to breakdown. The 73.6 Mc signal amplitude indicates breakdown began at 82 km and ended at 87 km slant range (78.5 km and 83 km altitude). Since the potential required for breakdown is a function of frequency and pressure[2], different ranges of breakdown as a function of altitude are expected for the two radio frequencies.

With the exception of breakdown, the antennas used on Nike-Apache 14.31 performed very successfully as predicted. The 24.53 Mc shroud antennas provided a field strength 14.3 db below a dipole driven at the same power level. Since this is the first time that shrouds have been used at 24.53 Mc there were no other independent measurements that could be used for comparison.

The 73.6 Mc shroud antenna provided a field strength 13.9 db below a dipole. This value was computed by assuming that the actual power delivered to the measured value of the shroud impedance was supplied to a dipole on the rocket. The field strength actually obtained from the shrouds was computed from the measured characteristics of the receiving antenna and the observed signal levels obtained. This value is in excellent agreement with the best flight results of standard 73.6 Mc shroud antennas used for SSD tracking[9] at Wallops Island, Virginia. However, this value disagrees with 76 Mc data on similar shroud antennas reported by

Richard[4] of the Ballistic Research Laboratories, Aberdeen, Maryland.

Nike-Apache 14.32

The graphs of received signal amplitude versus slant range for Nike-Apache 14.32 are shown in Figures 12 and 13. To avoid breakdown, as observed in the Nike-Apache 14.31, (Figures 10 and 11) approximately 5 db of attenuation was placed between each transmitter and its antenna system. A timer was provided to remove the attenuation after the rocket passed through the breakdown region. The resulting increase in signal amplitude is shown by the abrupt change at 102 km slant range.

Computations, using the power-input to the shroud antennas in flight and the measured characteristics of the receiving antennas on the ground, indicated that the 24.53 Mc shroud antennas gave a field strength 14.8 db below a dipole. Similar computations indicated that the 73.6 Mc shrouds were 13.6 db below a dipole during this flight. These values are in close agreement with the values obtained for the Nike-Apache 14.31. The power level applied to the 73.6 Mc shroud antennas, after removal of the attenuation was about 3 db less than for 14.31 but a more directive receiving antenna was used on the ground.

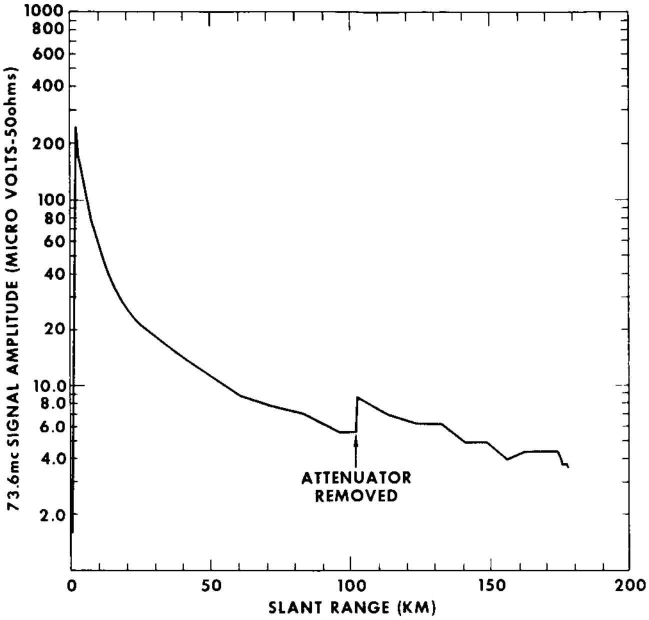

FIGURE 12

73.6 Mc. Received Signal Amplitude for Nike Apache 14.32

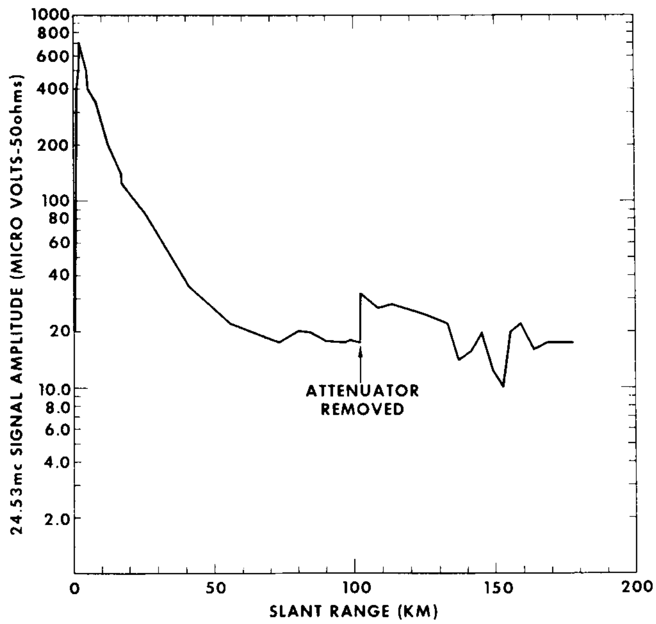

FIGURE 13

24.53 Mc. Received Signal Amplitude for Nike Apache 14.32

VI. CONCLUSIONS

The present investigation of the application of shroud antennas to the rocket-borne propagation technique resulted in these major accomplishments:

1. The operating frequency-range of the shroud antennas has been extended into the HF region. By doubling the physical length of the 73.6 Mc shrouds, the radiating efficiency obtained at 24.53 Mc was comparable with that obtained at the higher frequency. The longer antennas apparently did not affect the rocket performance, due probably to the fact that the frontal area, contributing to the rocket drag, remained the same.
2. Computations indicate that suitable changes in the geometry of the shrouds would result in antennas with the same efficiency for frequencies as low as approximately 10 Mc without appreciably increasing rocket drag.
3. Matching techniques have been developed that provide efficient performance and predictable signal levels.
4. A simple method has been successfully used to prevent R. F. breakdown at critical pressures.
5. Agreement between predicted and observed signal strength indicate that the terminal impedance of the shrouds have been adequately measured on a ground plane.
6. It was found that the performance of the shroud antennas can be predicted satisfactorily by small loop-antenna theory.

7. It was demonstrated that shroud antenna matching networks can be adjusted prior to installation on the rocket, and that only a simple built-in monitoring is required to insure proper adjustments at the time of the launching.

VII. ACKNOWLEDGEMENTS

The authors are indebted to Mr. J. E. Jackson and Dr. S. J. Bauer for many helpful suggestions during the preparation of this report. We wish to thank Mr. Billy Gammill of the New Mexico State University for helpful information supplied.

We also acknowledge several helpful discussions with Mr. Victor W. Richard of the Ballistic Research Laboratory.

REFERENCES:

1. Seddon, J.C., "Propagation Measurements in the Ionosphere with the Aid of Rockets." J. Geophys. Res. 58(3):323-335, Sept. 1953
2. Jackson, J.E. and Kane, J.A., "Breakdown and Detuning of Transmitting Antennas in the Ionosphere." Upper Atmosphere Research Report No. XXXVI, NRL Report 5345
3. Bauer, S.J. and Jackson, J.E., "Rocket Measurements of the Upper Ionosphere by a Radio Propagation Technique." NASA Technical Note D-1123
4. Richard, V.W., "The Shroud Antenna." Ballistic Research Laboratory Memorandum Report No. 1283, June 1960
5. Terman, F.E., Radio Engineer's Handbook, p. 813, McGraw-Hill Book Company, Incorporated.
6. Terman, F.E., Radio Engineer's Handbook, p. 774, McGraw-Hill Book Company, Incorporated
7. Bruene, W.B., "How to Design R-F Coupling Circuits," Electronics, Volume 25, No. 5, May 1952
8. Richard, V.W., private communication
9. Gammill, B., private communication

APPENDIX

The Measurement of the Terminal Impedance of the Shroud Antenna

To measure the terminal impedance of the shroud antenna, advantage was taken of the symmetry of the set of shrouds. By mounting a shroud on a suitable mock-up (half-rocket) which was placed on a ground plane (an aluminum sheet about 15 ft. square appears to be adequate for small rockets) the terminal impedance of an individual shroud with its electrical image can be adequately simulated.

If space is available under the ground-plane for an impedance bridge to be used, the measurements can be made near the shroud without disturbing the field of the antenna. Although it would be possible to measure the impedance through an arbitrary length of cable it is generally more convenient to use a half-wave length. An additional piece of cable was connected in series between the cable normally supplied with the shroud and the impedance bridge. The additional cable had the same characteristic impedance as the shroud cable. The length of the added cable was adjusted until the impedance bridge indicated that the electrical length of the whole cable was precisely one-half wave length at the operating frequency. This was done by leaving the end of the cable open and adjusting the cable length for a high impedance and zero reactance at the bridge end of the cable. This procedure includes the electrical length of the bridge terminals in the half-wave length.

After the cable had been adjusted to a half-wave length it was connected to the shroud terminals. The impedance presented by the cable connected to the antenna was measured on the bridge. Since the values obtained indicated that the antenna impedance was higher than the unterminated cable impedance, special care had to be taken in determining the shroud impedance. The bridge used for these measurements indicated the parallel components of the impedance. It was assumed that the resistive component of the antenna impedance was in parallel with the resistive component of the half-wave cable as measured with the cable unterminated. The assumption was also made that the reactive component of the antenna would be essentially the same as that measured through the cable. A dummy antenna load as computed using the above assumptions was built and substituted for the antenna. When the dummy antenna was measured through the half-wave cable the impedance read at the bridge was the same as when the actual antenna was connected at the end of the half-wave cable.

The value obtained by this substitution technique for the 73.6 Mc shroud was 4220 ohms in parallel with 191 ohms inductive reactance, which is equivalent to an 8.6 + j191 ohms series impedance.